



## Fertilizer improves seed and oil yield of safflower under tropical conditions



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### ABSTRACT

Safflower (*Carthamus tinctorius* L.) has gained importance as an oilseed crop due to its hardiness and oil, which can be used in the production of biofuels. Studying proper crop management methods is highly important for the development of safflower in Brazil, since applying fertilizers correctly and using the appropriate time are efficient ways to achieve higher yield. Thus, the objective of this study was to evaluate safflower yield components, seed yield and oil content in two growing seasons. Two experiments under dryland conditions were conducted in 2014 in Cascavel, PR, Brazil. A randomised complete block design with three replications was used. Five rates of NPK fertilizer were used (0, 200, 400, 600 and 800 kg ha<sup>-1</sup> of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O formula 4-14-8) in two growing seasons (autumn and winter). Even in a Rhodic Acrudox with high concentrations of P and K, the application of NPK fertilizer in the furrow improved seed yield and oil yield in the autumnal growing season. Safflower seed yield averaged 2068 and 3820 kg ha<sup>-1</sup> in autumn and winter, respectively. The application of NPK fertilizer to safflower in the autumnal growing season significantly increased oil content (23.9%). The linear plateau model predicted increased yield with NPK rates <652 kg and <610 NPK ha<sup>-1</sup>, resulting in seed yield and oil yield of approximately 4374 kg ha<sup>-1</sup> and 1048 kg ha<sup>-1</sup>, respectively. Safflower seems promising as an alternative oilseed crop for Southern Brazil when seeded in autumn with basic fertilization.

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### 1. Introduction

Due to the global demand for bio-energy species, safflower (*Carthamus tinctorius* L.) stands out in Brazil as an alternative in the production of food and energy (Santos and Silva, 2015; Santos et al., 2015). Due to its hardiness and favorable agronomic characteristics, safflower can be an alternative for arid areas, since it can be used in crop rotation for being tolerant to drought and having a deep root system (Merrill et al., 2002; Lovelli et al., 2007; Hussain et al., 2015).

One of the most efficient ways for safflower to develop in tropical conditions with high efficiency is by applying fertilizers correctly. However, one needs to know the proper amount of fer-

tilizer to apply and also when and how to perform the application in a way that meets the growing needs of the environment. In tropical soils, farmers usually rely on the short-term positive effects of chemical fertilizers to maintain high crop yield.

In Brazil, safflower is an option for the second crop (off-season). Due to shortage of time and irregular rainfall, farmers prefer to use little or no fertilizer at sowing, which can hinder the performance of crops (Bicudo et al., 2009). Safflower has nutritional requirements that are similar to those of wheat, but it can access deeper layers of nutrients due to its root system (Haghighati, 2010). All nutrients are important for the crop, however, studies indicate that basic fertilization with nitrogen (N) (Dordas and Sioulas, 2008; Yau and Ryan, 2010; El-Mohsen and Mahmoud, 2013), phosphorus (P) (Abadi and Gerendas, 2011; Golzarfar et al., 2012) and potassium (K) (Hussien and Wuhaib, 2010; Palizdar et al., 2011; Abbasieh et al., 2013) has been highly efficient on safflower growth throughout the world. The effects of fertilization on safflower development

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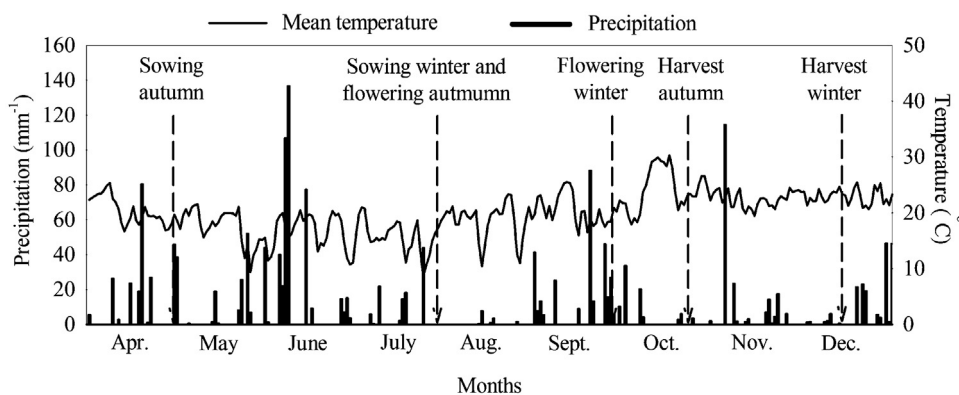


Fig. 1. Behavior of meteorological variables of precipitation and mean temperature during safflower cultivation seasons in Cascavel, PR, Brazil, in 2014.

**Table 1**  
Soil chemical attributes (0–2 dm) in two growing seasons.

Soil	P (Mehlich 1) (mg dm <sup>-3</sup> )	pH (CaCl <sub>2</sub> )	cmol <sub>c</sub> dm <sup>-3</sup>				CTC	V (%)
			K	Ca	Mg	H + Al		
Autumn season	12.8	5.2	1.3	4.6	2.2	5.7	14.3	59
Winter season	19.4	5.4	0.8	4.5	2.8	5.2	13.3	61

have not been extensively studied, especially in Brazil, and existing studies are limited to controlled conditions that do not focus on oil production (Bonfim-Silva et al., 2015; Anicésio et al., 2015).

In addition to fertilization, time of sowing and the period of nutrient uptake directly interfere in safflower crop productivity (Mündel, 2004), since the plants can complete their growth cycle before the beginning of the dry months due to increased metabolic activity and rapid growth, which can change their phenotype to escape drought conditions (Sherrard and Maherli, 2006).

Safflower yield and oil components may be affected by many factors, such as genotype, ecology, morphology, physiology and fertilization (Cosge et al., 2007). The time of sowing has great impact on safflower oil properties (Senkal et al., 2016).

Several studies report that sowing safflower in autumn may lead to a significant increase in seed yield (Koutroubas et al., 2004; Yau, 2007; Golzarfar et al., 2012). Thus, due to the low fertility of tropical soils, low volume of scientific information on the subject and the hypothesis that safflower response to basic fertilization is dependent on sowing seasons, the aim of this study was to evaluate the effects of different fertilizer rates on yield components, seed yield and safflower oil content in two growing seasons.

## 2. Materials and methods

### 2.1. Location and climatic conditions

Two experiments were conducted in 2014 in Cascavel, Paraná State, Brazil, whose geographic coordinates are 24°56'40"S and 53°30'31"W with an average altitude of 715 m. The behavior of the meteorological variables of the experiment is shown in Fig. 1.

The soil of the experimental area was classified as Rhodic Acrudox (Soil Survey Staff, 2014). The experimental area had been managed in a no-tillage system for over 20 years, with corn or soybean crops in the summer and oats or wheat crops in the fall/winter seasons. Soil properties are presented in Table 1.

### 2.2. Experimental set-up

The first growing season started with sowing on April 30, 2014 (autumn), and the second one on July 30, 2014 (winter). In the first

season, safflower was sown after soybean. Sowing in winter at low temperatures may cause negative effects on plant growth and on the seed filling stage.

The safflower genotype IAPAR was sown manually, leaving 10 plants per meter after thinning (222 thousand plants per ha).

### 2.3. Treatments and experimental design

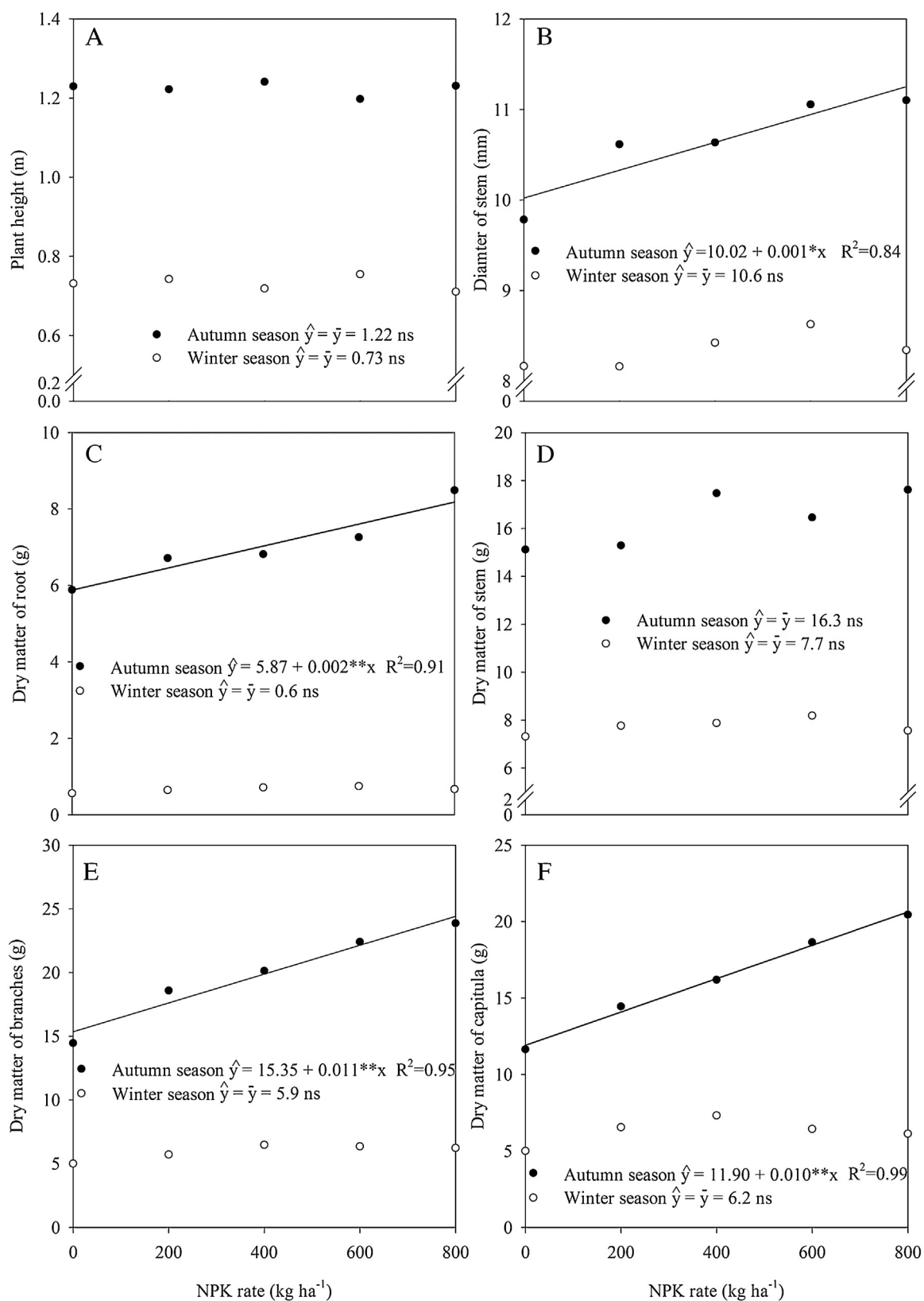
A randomised complete block design with three replications was used. Each block was divided into five plots, to which five rates of N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O (4-14-8) fertilizer were applied (0, 200, 400, 600 and 800 kg ha<sup>-1</sup>). Each plot consisted of four rows measuring 4 m long, with spacing of 0.45 m between rows.

### 2.4. Traits evaluated

When the flowering stage reached 50%, at 80 and 60 days after emergence in the autumn season and winter season, respectively, plant height was determined by measuring the distance between the soil level and the plant apex with a graduated tape. Six random plants were measured within each plot. The number of branches and capitula per plant was also determined when flowering reached 50% from six random plants from each plot. Stem diameter was also determined, by measuring the basal region of the stem with a digital caliper. The safflower plants were separated into stem, branches, roots and capitula in the flowering stage and dry matter was determined by drying at 65 °C until constant weight was obtained.

Harvest took place after 160 and 140 days after emergence in the autumn and winter seasons, respectively, and seed yield was determined. Plants were collected from a linear meter of each plot and manual threshing and cleaning of the seeds were performed. Values were expressed in kg ha<sup>-1</sup>. The 1000-seed weight was determined by counting sub-samples of 100 seeds per plot. The samples were weighed on a precision scale to two decimal places. Moisture content was determined gravimetrically by drying a subsample for 24 h at 105 °C and corrected to 12%. The 1000-seed weight was determined in accordance with the Rules for Seed Analysis (Brasil, 2009).

Oil content was determined by TD-NMR in an SLK-SG-200 spectrometer (Spin Lock Magnetic Resonance Solutions, Malagueño,



**Fig. 2.** Plant height (A), stem diameter (B), dry matter of root (C), dry matter of stem (D), dry matter of branch (E) and dry matter of capitula (F) of safflower according NPK rates (4–14–8) in two growing seasons. ns: not significant. \*\* Significant at  $P \leq 0.01$  probability. \* Significant at  $P \leq 0.05$  probability.

Córdoba, ARG) at 25 °C, equipped with a permanent magnet of 0.23 T (9 MHz for 1H) and a probe with 13 mm × 30 mm useful area. Condor IDE software was used with CPMG pulse sequence and

Qdamper (Colnago et al., 2011). Results were expressed on a dry basis (% DB). Oil yield (kg ha<sup>-1</sup>) was calculated as the product of oil content and seed yield.

**Tabela 2**  
Sources of variation, yield components, seed yield and oil yield of safflower.

Sources of variation	PH	SD	DMR	DMS	NB	DMB	NC	DMC	SY	TSW	OIL	OY
Winter	1.22	10.6	7.0	16.3	6.4	19.8	12.5	16.2	3820	68.7	23.5	907
Autumn	0.73	8.3	0.6	7.7	6.8	5.9	9.3	6.2	2068	48.4	24.2	520
LSD (0.05)	0.02	0.4	0.9	1.1	0.5	3.16	1.6	2.4	458	7.96	1.1	122
0	0.98	8.9	3.2	11.2	6.1	9.7	9.4	8.3	2700	59.5	23.4	636
200	0.98	9.3	3.6	11.5	6.7	12.1	10.2	10.4	2669	57.4	24.3	658
400	0.97	9.5	3.7	12.6	6.8	13.2	11.4	11.7	2680	54.4	23.6	634
600	0.97	9.8	3.9	12.3	6.7	14.3	11.8	12.5	3403	56.2	23.9	848
800	0.97	9.7	4.5	12.3	6.8	15.04	11.9	13.2	3268	65.1	23.9	792
LSD (0.05)	0.04	0.7	1.4	12.5	0.8	5.0	2.5	3.8	725	12.5	1.7	194
S × NPK	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS: not significant. LSD: Least significant difference by  $t$ -test at  $P \leq 0.05$  probability. PH: Plant height in cm; SD: stem diameter in mm; DMS: Dry matter of stem in  $\text{g plant}^{-1}$ . NB: Number of branches; DMB: Dry matter of branches in  $\text{g plant}^{-1}$ ; NC: Number of capitula; DMC: Dry matter of capitula in  $\text{g plant}^{-1}$ ; SY: seed yield in  $\text{kg ha}^{-1}$ ; TSW: thousand seeds of weight of,  $\text{g plant}^{-1}$ ; OIL: Oil content in%; OY: oil yield in  $\text{kg ha}^{-1}$ .

### 2.5. Statistical analyses

Statistical analysis was conducted using a randomised complete block design, with a factorial arrangement. Mean separation was performed by applying the  $t$ -test at  $P \leq 0.05$  level of significance. Fits that provided a coefficient of determination higher than 70% and minimal significance level of  $P \leq 0.05$  were considered satisfactory for the regression models. Regression analysis was performed in Sigma Plot 11.0 software (Jandel Scientific, Sausalito, CA, USA). Linear response plateau was used for seed yield and oil yield, using SAS PROC NLIN (SAS Institute, 2014).

## 3. Results and discussion

Safflower grown in autumn received approximately 1.170 mm rainfall, which is above the rainfall level in the winter season (600 mm) and also above the amount required throughout the cycle for optimal growth, since safflower requires 800–1000 mm (Oyen and Umali, 2007), especially due to its slow initial growth characterized by the rosette stage. However, according to Oyen and Umali (2007), this crop may also grow in regions of low water availability and dry climate under minimal rainfall requirements (300 mm) before reaching the flowering stage. In this sense, the time of sowing is the factor that most affects safflower crops, as a delayed or early sowing could compromise productivity (Mohamadzadeh et al., 2011), leading to reduction of the canopy area and also diseases after flowering.

### 3.1. Yield components

Growth components of the vegetative phase were affected ( $P \leq 0.05$ ) by fertilization, especially in autumn, except for plant height and stem dry matter (Fig. 2A–F). Janmohammadi et al. (2016) also studied safflower grown in autumn and observed that the application of fertilizers improved growth characteristics. In this study, except for the number of branches, yield components were higher in the autumn season (Table 2). However, there was a difference of 67% in plant height and 119% in stem dry matter between both growing seasons.

Similarly, accumulation of dry matter of root, branches and capitula, and also stem diameter benefited from sowing in autumn (Table 2). This is due to low rainfall after sowing, since the growing period is highly important to the safflower crop, because that is the period in which plants are more severely affected by water stress (Hussain et al., 2015). Stem diameter was not sensitive to intermediate fertilizer rates, but it was strongly affected by the rate of 800 kg of NPK fertilizer  $\text{ha}^{-1}$  (Fig. 2B). Besides, the low accumulation of dry matter in the winter season is also related to the uptake of nutrients, especially nitrogen, whose absorption, accumulation, partitioning and translocation rates in safflower plants are affected

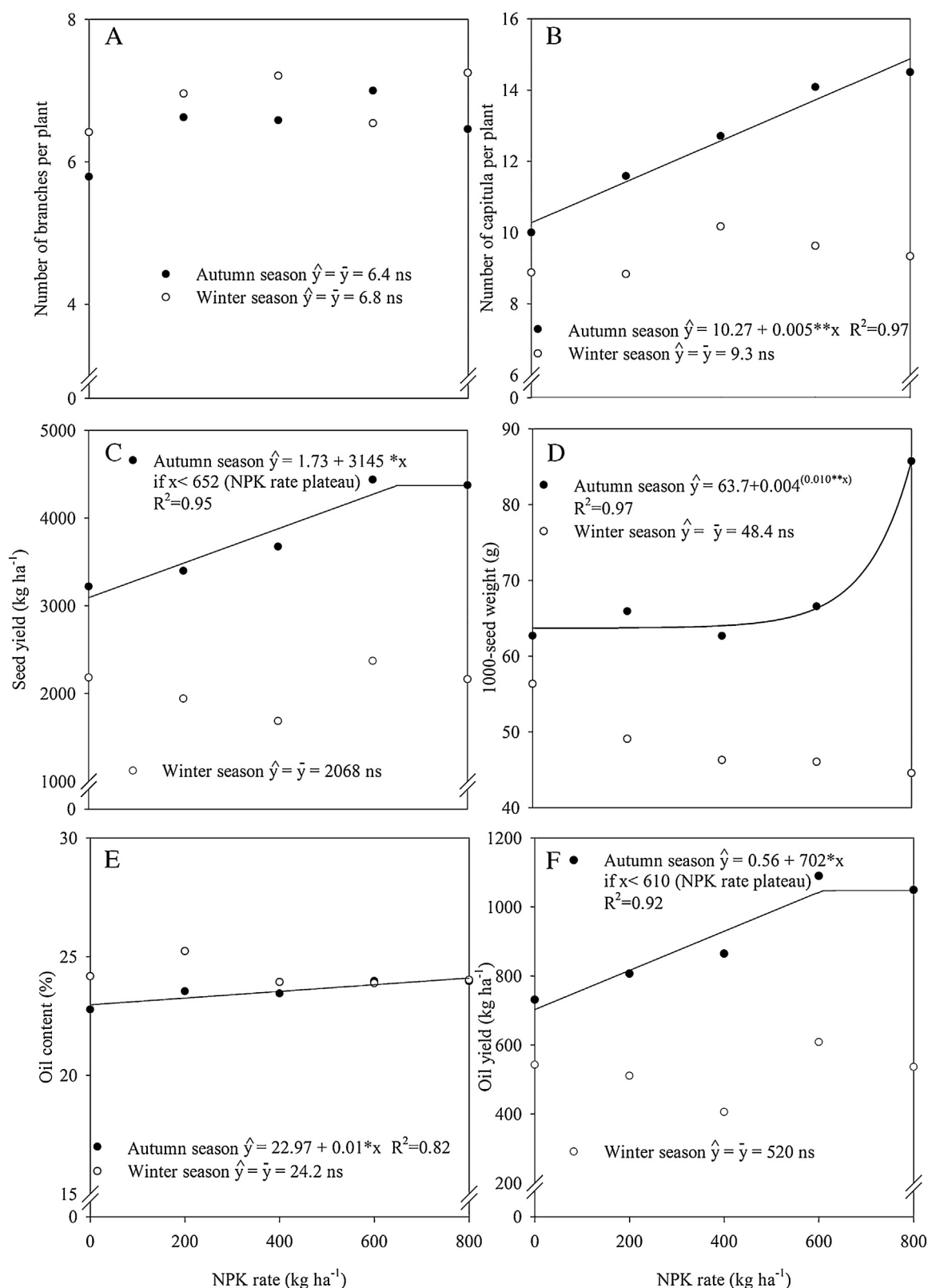
in drought conditions (Dordas and Christos, 2009). Reduction of the root system and relative growth rate was observed in safflower genotypes under water deficit conditions (Hojati et al., 2011). Bellé et al. (2012), in Southern Brazil, observed lower dry matter accumulation when sowing in summer than in the autumn-winter season due to high levels of evapotranspiration. Positive results of autumn sowing have been reported in the literature (Koutroubas et al., 2004; Yau, 2007).

Increasing rates of NPK fertilizer resulted in increased dry matter accumulation during the autumn season, except for stem dry matter (Fig. 2D). Safflower has extensive ramifications and its dry matter accumulation depends not only on plant height and stem diameter (Koutroubas et al., 2004), as observed in this study, but also on branches and leaves, which provide an increase in the number of capitula, which will likely result in higher seed yield. The availability of nutrients, particularly nitrogen, possibly allowed greater accumulation of nutrients, resulting in dry matter accumulation in plant parts during the flowering stage. Dordas and Christos (2009) observed that nitrogen fertilization increased dry matter production in 24% until anthesis. Anicésio et al. (2015), under controlled conditions, also noted that rates of N and P positively influence shoot dry matter. Bonfim-Silva et al. (2015) observed that nitrogen fertilization influenced plant growth in a Cerrado soil under controlled conditions.

The results demonstrate that the uptake of nitrogen by the plant is adapted according to the different rates of fertilizer applied. Safflower has a well-developed root system, so its roots can explore deeper layers of the soil with greater absorption of nutrients, providing enhanced root dry matter results (Dordas and Sioulas, 2008). Hussien and Wuhaib (2010) reported positive results of potassium fertilization rates on root dry matter.

Although the number of branches was not affected by fertilization (Fig. 3A), the NPK rates increased the number of capitula per plant during the autumn season (Fig. 3B). Thus, the number of branches was not responsible for increased production of capitula, once fertilization offset resulted in a greater number of capitula per branch. Dordas and Sioulas (2008) and Abbadi and Gerendas (2011) report that increasing fertilizer rates provided better results concerning to the number of capitula per plant. In this study, the result obtained in the winter season matches that obtained by Lovelli et al. (2007), who reported water stress as responsible for reducing the number of capitula per safflower plant. Studies by Salera (1996) show that late sowing leads to a significant decrease in the number of capitula per plant due to high temperature during the growing season.

For the 1000-seed weight (Fig. 3D), the crop sown in autumn showed an upward exponential trend with the fertilization rate of 800 kg NPK  $\text{ha}^{-1}$ . Safflower 1000-seed weight showed low sensitivity to low rates of fertilizer in autumn. The weight increase in seeds subjected to fertilizer application can be attributed to the improved



**Fig. 3.** Number of branches per plant (A), number of capitula per plant (B), seed yield (C), 1000-seed weight (D), oil content (E) and Oil yield (F) according NPK rates (4–14–8) in two growing seasons. ns: not significant. \*\* Significant at  $P \leq 0.01\%$  probability. \* Significant at  $P \leq 0.05$  probability.

supply of photo assimilates resulting from the abundance of essential elements, which are utilized for enlargement of the sink cells (Dordas and Sioulas, 2008). According to Koutroubas et al. (2004), the translocation of stored assimilates from vegetative parts to the

seeds for seed-filling and seed weight compensation influences the variable, making the correlation with seed yield impossible in some cases. The 1000-seed weight is also affected by plant characteristics and genes (Brăileanu et al., 2013). Moreover, there was a 41% dif-



ference in the 1000-seed weight between the first season (autumn, 68.7 g) and the second (winter, 48.5 g).

### 3.2. Oil content

In what concerns to oil content (Fig. 3E), which is a determining factor for oilseed crops, basic NPK fertilization caused an increase of 23.9% in the autumn crop. However, there was only a difference of 0.8% from the average value of the winter crop (24.1%), which demonstrates the low variability of this variable, which is due to maximum transfer of assimilates for seed development instead of producing more vegetative parts and seeds, as commonly found in the literature. The analysis of variance (ANOVA) did not detect significant differences between both seasons (Table 2). According to Rathke et al. (2005), optimizing the oil content involves balancing protein synthesis and crude oil levels in the seeds as well as energy and carbon dioxide (CO<sub>2</sub>), because nitrogen-based fertilizers may affect such synthesis.

The values reported in this study are below the 35–45% range, which is the average content range found in the literature (Kaya et al., 2003; Mahasi et al., 2009). That is due to the genotype used in the study, which presents low oil content. Elfadl et al. (2009) also observed that the obtained oil content in temperate conditions with nitrogen rates was low (22%), which, according to the authors, is due to the crop used in the study and the environment.

### 3.3. Seed yield and oil yield

Seed yield benefited from the NPK fertilization only in the autumn crop (Fig. 3C), the time in which the use of nutrients was higher, since in the winter crop the contrasting conditions of temperature and precipitation were crucial to productivity reduction. However, the average yield (2068 kg ha<sup>-1</sup>) (Table 2) observed in the winter crop is within the 1000–3300 kg ha<sup>-1</sup> range, obtained in the Pampas region of Argentina (Quiroga et al., 2001), in Potenza, Italy (Lovelli et al., 2007) and in Orissa, India (Kar et al., 2007). The linear plateau model predicted an increasing relative yield with NPK rates <652 kg NPK ha<sup>-1</sup>, resulting in relative seed yield of approximately 4374 kg ha<sup>-1</sup>. The result of this study also agrees with the results reported by Ghanbari-Odivi et al. (2013), in which safflower showed higher productivity with sowing in May (autumn) than in July (winter). Early sowing combined with favorable conditions and a long growing season results in increased seed development and yield (Adisarwanto and Knight, 1997). Positive results on autumn sowing have been reported in the literature (Koutroubas et al., 2004; Yau, 2007). Contrasting climate conditions and the lower concentrations of P and K in the winter season caused the NPK fertilization to be inefficient.

Oil yield is a combination of seed yield and oil content, so it was highly influenced by seed yield ( $r=0.98$ ;  $p<0.0001$ ) (Fig. 2E). The linear plateau model predicted an increasing relative yield with NPK rates <610 NPK ha<sup>-1</sup>, resulting in relative oil yield of approximately 1048 kg ha<sup>-1</sup>. Even having lower oil content than that reported in the literature, the high seed yield observed in the autumn crop was responsible for an efficient oil yield in this study.

Safflower flowering in the winter season occurred under good rainfall conditions (Fig. 1), however, the water deficit during the plant development stages limited productivity, as also noted by Istanbuluoglu et al. (2009). Singh et al. (2016), in the southern plains in New Mexico, USA, observed a productivity decrease above 70% in safflower cultivated under irrigated conditions in comparison to that cultivated in a dry farming system.

The plateau model indicated that a fertilizer rate slightly higher than 600 kg NPK ha<sup>-1</sup> would be sufficient for safflower seed yield and oil yield, with 24 kg N ha<sup>-1</sup>, 108 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> and 48 kg K<sub>2</sub>O ha<sup>-1</sup>. A lower amount of N (24 kg ha<sup>-1</sup>) was enough for

achieving satisfactory yield. Nitrogen is one of the most important nutrients for crop production. Growth is reduced when nitrogen level in the soil is not optimal. In the past, fertilizers using 20–50 kg N ha<sup>-1</sup> were described as appropriate for semi-arid rainfed agriculture in California (Knowles and Miller, 1960). Yau and Ryan (2010) carried out a multi-year study in the Mediterranean environment in which safflower did not respond to N application in a no-tillage system. Dordas and Sioulas (2008) applied nitrogen fertilizer rates of 100 and 200 kg ha<sup>-1</sup> and obtained increased safflower seed yield even though their soil NO<sub>3</sub> levels were higher. The discrepancy found in the nitrogen fertilizer requirement for the safflower crop may be related to the soil management system in which the crop is managed, different genotypes, preceding crop, residual nitrogen content in the soil and climatic conditions.

It is assumed that the results are related to the ability of the safflower crop and to the soil with high concentrations of P and K. In the winter season, water stress in the early stages may have reduced nutrient uptake by the roots and translocation in the plant due to the low perspiration rate, which decreased active transport and impaired membrane permeability (Hu and Schmidhalter, 1998), causing contrasting results of seed yield and oil yield between autumn and winter seasons.

## 4. Conclusions

Safflower seems promising as an alternative oilseed crop for Southern Brazil when sown in autumn with basic fertilizer. Even in a Rhodic Acrudox with high concentrations of P and K, the linear plateau model predicted an increasing relative yield with NPK rates <652 kg and <610 NPK ha<sup>-1</sup> resulting in relative seed yield and oil yield of approximately 4374 kg ha<sup>-1</sup> and 1048 kg ha<sup>-1</sup>, respectively.

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